

110-72J-1

SUMMARY OF ENGINE DESIGN AND ANALYTICAL
STUDIES TO MATURE THE 1137400E ENGINE BASELINE

Project 110, Paragraph 3

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Prepared by:

D. E. Kleinert
W. A. Lester

May 1972

(NASA-CR-132230) SUMMARY OF ENGINE
DESIGN AND ANALYTICAL STUDIES TO MATURE
THE 1137400E ENGINE BASELINE (Aerojet
Nuclear Systems Co., Azusa, Calif.)
30 p HC \$3.50

N73-24667

Unclas
CSCL 21F G3/22 17715

D. Buden
D. Buden, Manager
Engine Design & Analysis
Department

PREFACE

This report contains a short introduction, conclusion recommendation, and reference(s) for the work performed under Project 110, Paragraph 3-f-a through i.

The applicable references (Appendixes 1 through 7) were considered too voluminous for inclusion in this report (they contain approximately 1000 pages) and are available under document identification 110-f-3a through 3i , in Storage Box No. 6.

PROJECT 110 - SYSTEMS ENGINEERING

PARAGRAPH 3

1. INTRODUCTION

(a) The purpose of this activity was: "Perform Engine Design and Analytical Studies to Advance the Maturity of the 1137400E Flight Engine Baseline. This included the packaging of numerous related components into integral module arrangements compatible with engine design requirements. Secondly, this activity coordinated the applied mechanics and thermal analysis effort related to engine design. Remaining activity was the conceptual design study for a propulsion module".

(b) Work accomplished is documented in reports as referenced in and updated by the individual project reports in the Appendices for each sub-paragraph of Paragraph 3.

(c) The degree of completion is as specified in the individual sub-paragraph project reports.

(d) The external factor influencing the engine design progress most was the contract termination effective date of February 18, 1972.

(e) Names of personnel performing the work:

B. Breindel
H. J. Bronner
I. K. Hall
D. E. Kleinert
E. V. Krivanec
W. A. Lester
J. H. Oates
G. O. Patmore
W. E. Stephens
K. E. Unmack
D. Vronay

2. Conclusions

(See sub-paragraph project reports)

3. Recommendations

(See sub-paragraph project reports)

4. References

(See Appendices)

Project 110-f-3.a

1. INTRODUCTION

Project activity for the period March 1971 through February 1972 was devoted to the updating of the 1137400 Engine Assembly drawing to the "E" Revision. The changes to the engine configuration were related to revised component envelopes, elimination of bellows in certain lines, and incorporation of quad-pack valve modules. This revision became the engine baseline configuration in conjunction with the related schematic drawing #1137401F and criteria established in Appendix I, Item 3. Personnel directly involved with these activities were:

E. Krivanec

D. Kleinert

W. Harrington

2. CONCLUSIONS

The "E" Revision drawing successfully incorporated the redesigned modules and revised components. Bellows were deleted from all lines except the propellant inlet lines, the cooldown line and the stage tank pressurization line in the region of the gimbal plane and the pump discharge line.

3. RECOMMENDATIONS

While significant improvements to the engine assembly have been realized from this update activity, it is strongly recommended that further efforts be conducted in the areas of component and module support design. Also the maintainability of the critical components could be improved.

4. REFERENCES

(See Appendix I)

Project 110-f-3.b

1. INTRODUCTION

The project activity during the report period for preparing an informal internal draft of Data Item E-105 for the baseline configuration was not in process of being updated at time of contract termination.

2. CONCLUSIONS

None

3. RECOMMENDATIONS

None

4. REFERENCES

None

Project 110-f-3.c

1. INTRODUCTION

While several reference engine assembly configurations have been completed, relatively little design effort has been devoted to auxiliary support structures for the components, modules, and ducts. Serious design and analysis was initiated during this report period for this task and drawing 1138645, Sheets 1 through 3, was completed which covers several module brackets and some major duct supports. Not all of the component, module, and duct support structures were completed.

Another support design concept was completed (Appendix II, item 1) which employed the use of wire mesh support pads. These pads served to restrain the component dynamically while allowing thermal displacement to reduce loading effects on adjacent critical components.

Personnel involved with these designs were:

K. Unmack
D. Kleinert
W. Harrington
J. Oates

2. CONCLUSIONS

The support bracket concepts depicted by drawing 1138645 resulted from PFS structural analysis which defined the support requirements for the 1137400 E engine configuration commonly referred to as Support System #9. Subsequent analysis directed toward eliminating bellows from high pressure lines required that the pump discharge module support be changed to allow X direction (longitudinal) deflections in addition to rotations. The 1138645 concept, when incorporating this change, is then applicable to the 1137400 E engine with bellows removed from the pump discharge line.

Project 110-f-3.c (Continued)

3. RECOMMENDATIONS

The 1138645 design concepts appear to be promising and should be proposed with the aforementioned changed.

4. REFERENCES

(See Appendix II)

Project 110-f-3.d (1) thru (5)

1. Introduction

a. Purpose of the Activity

(1) Perform analytical design of the engine (Applied Mechanics and Thermal).

(2) Provide summaries for the E-105, S-031, S-036, S-038, S-039 and S-047 Data Items to be published.

b. Gross content of material preserved - Thermal, Structural, Dynamics, Loads, and Mass Properties Analyses as applied to analytical design of the engine.

c. Degree of completion is consistent with the current level of maturity of the 1137400E engine. Major missing items are all those summaries required in 1.a.2 above. These were not completed as the various reports were scheduled for publication after the program termination date.

d. Personnel performing the work:

H. J. Bronner	N8610
I. K. Hall	N8120
J. H. Oates	N8610
G. O. Patmor	N8610
J. G. Schumacher	N8120
W. R. Thompson	N8110
K. E. Unmack	N8610
D. F. Vronay	N8120
E. A. Warman	N8140

2. Conclusions

Project 110-5-3.d (1) Status:

Thermal Analysis (S-031)

Analyses performed emphasized the effects of space environment on both steady state and transient response temperatures. Solar heating at 0.72 Au was found to be the most severe design condition where temperatures of aluminum components without special emissivity enhancement treatment, and/or other protective measures, exceeded assumed service temperatures. It was also found that the electronics units cannot be located as shown on 1137400E with temperature control solely by passive means.

Details of the analyses may be found in APPENDIX III, Item 1.

Project 110-f-3.d (2) Status:

Structural Analysis (S-036)

No activity, work was scheduled for completion after program termination date.

Project 110-f-3.d (3) and (4) Status:

Dynamics Analysis (S-038) and Loads Analysis (S-039)

Analyses completed indicate the feasibility of the Propellant Feed System (PFS) using the support system designated number 9. Nuclear Space Operation (NSO) dynamic loads are larger than Launch Vehicle Operations (LVO) dynamic loads and determine the design requirements. Loads and response acceleration levels were obtained from the analyses and are reported in detail in APPENDIX III, Item 2.

Thrust Train Analyses, while demonstrating the adequacy of the engine design, revealed serious deficiencies in the Engine Assembly Support (EAS) during LVO. Responses at the unsupported ends of the engine are excessive. Additional analysis and design effort is required on the EAS to ensure that all responses are within reasonable bounds. Details of the analysis are reported in APPENDIX III, Item 3 and Project 110-f, Paragraph 3.h. Preliminary analysis indicates that interface loads for a TPA malfunction condition are generally higher than for normal operation. Further analysis is required to better define the problem. Details of the analysis may be found in APPENDIX III, Item 4. Gimbaling loads data were not generated as that effort was scheduled for completion after the program termination date.

Project 110-f-3.d (5) Status:

Mass Properties Analysis (S-047)

Weight status and target weights were compiled for the 1137400E engine, however, the mass properties report was not issued. Further details may be found in APPENDIX III, Item 5.

3. Recommendations

None

4. References

(See APPENDIX III)

Project 110-f-3.e

No effort - "no longer active."

Project 110-f-3.f

(1) Introduction

The project activity during the report period was to prepare for and conduct the engine portion of the engine and component design status review. This was accomplished as referenced in Appendix IV.

(2) Conclusions

None

(3) Recommendations

None

(4) References

See Appendix IV.

Project 110-f-3.g

1. Introduction

To further enable the engine configuration design to achieve its design objectives, a program of updating the reference concept was initiated.

Particular areas for concentrated effort were selected as follows:

- (1) Ease of critical component maintainability.
- (2) Improved reliability (such as bellows elimination).
- (3) Symmetrical fluid flow passages.
- (4) Identical and interchangeable components.
- (5) Reduction of line loads imparted to components.

The 400E configuration contains several design features that are generally undesirable such as non-interchangeable modules and non-symmetrical fluid passages. For example, each TPA module consists of the TPA, TBV, TDBV, and the PDKV/PDKVA. This module is not interchangeable with its counterpart in the propellant feed system nor is the TPA interchangeable within the two TPA modules. The "four-pack" valve modules are so arranged that the inlet and outlet passages are not symmetrical for each set of redundant valves resulting in different flow characteristics under a malfunction condition.

The plan for engine design update was to generally improve the existing configuration but as the selecting of the arrangement progressed, it became apparent that something more unique would have to be imposed in order to achieve the desired results. In all reality, it must be appreciated that under a given set of circumstances, the number of engine configurations completed (400 through 400E) had already extracted the full potential of this design approach.

Several months earlier a more unique engine design was studied under a limited effort which became known as the "radial engine." The name was derived from the fact that all the components and modules forward of the PVARA were arranged external to a central cylindrical thrust structure in a radial fashion. All the interconnecting ducts and lines are internal to the cylindrical thrust structure except those which come from the stage or lead to the PVARA. The primary objective of this approach was to isolate line loads from the various components and to facilitate maintainability. The early layouts of this concept were directed toward having individually maintainable components. However, this advantage was soon noted to be outweighed by the multiplexity of interconnecting internal lines and the number of structural penetrations. It was here that the "four-pack" module was utilized which significantly reduced these penetrations in the base thrust structure. Other advantages to the radial concept are:

1. Elimination of auxiliary module support structures.
2. Inherent protection of relatively thin walled ducts from shop damage or meteorites.
3. Subsystem shop checkout.
4. Flexibility of component redesign.
5. Minimum engine envelope.

A series of eight (8) engine layouts were completed (113970 thru 1139708) which explored variations of the basic theme pursuant to refining the concept and focusing attention on the problem areas of duct loading, engine length, accessibility, design flexibility, structural penetrations, and radiation protection.

Certain ground rules were compiled and respected to limit the overall effort and to eliminate the possibility of disturbing portions of the engine which are considered compatible with the engine's objectives. These ground rules were:

1. No configuration changes to any components except to eliminate non-identical assemblies.
2. Symmetrical fluid passages for all redundant systems
(See Project 127-f, Paragraph 3.e)
3. Provide a 14" length immediately forward of the biological shield for electronics.
4. Eliminate all bellows for fluid lines except where necessary for the propellant inlet ducts across the gimbal plane. (See Project 127-f, Paragraph 3.g.)

The basic radial engine theme was to provide a symmetrical fluid passage flow for the redundant systems and to locate each component or module such that it may be replaced with a minimum of disturbance to other parts of the engine. The analysis performed to date on duct loads with both ends fixed indicated that thermal shock, operating pressures, and manufacturing tolerances would produce end loadings which may fail either the duct or induce intolerable effects upon the connecting components. Either more flexibility was necessary or some means of "floating" one end had to be incorporated. From these analyses it became apparent that a minimum of interconnecting lines was desirable.

The brief description of each of the eight (8) engine layouts that follows contain identifying features that constitute the variations studied.

1. Engine Layout 1139701
 - a. Clustered TBV's and TDBV's with all large turbine drive ducts concentrated on one side.
2. Engine Layout 1139702
 - a. All components located radially in a progressive order according to functional operation.
3. Engine Layout 1139703
 - a. Minimum structural penetrations with TBV's and TDBV's separated from the TPA's.
4. Engine Layout 1139704
 - a. Minimum structural penetrations with TBV's, TDBV's and PDKV's included in TPA modules.
5. Engine Layout 1139705
 - a. TBV's and TDBV's grouped in pairs as separate modules.
6. Engine Layout 1139706
 - a. Same as 1139704 except TBV's mounted closer to TPA's.
7. Engine Layout 1139707
 - a. Basic radial component layout with TDBV's attached to the TPA's as a module.
8. Engine Layout 1139708
 - a. Same as 1139706 except PDKV's mounted over TPA's.

Personnel involved with these conceptual studies:

K. Unmack	D. Kleinert	
W. Lester	W. Harrington	K. Berset

2. Conclusion

While the radial engine concepts appeared to provide significant improvements in maintainability, envelope reduction, and reduced radiation effects, sufficient analysis had not been completed to assure that the thermal, and dynamic loads on the interconnecting ducts within the thrust structure could be tolerated. Early results indicated that the loads would be handled by allowing one end of each duct to float under restraint.

3. Recommendations

It is urged that an evaluation of the several radial engine concepts be completed and the optimum configuration be prepared in detail for institution as the recommended engine concept. The advantages offer significant value to make this the reference engine.

4. Reference

See Appendix V

Project 110-f-3.h

1. Introduction

- a. The purpose of this activity was:

To complete the conceptual design of a support structure for the engine to accept launch and boost loads, and to document the results of this effort in a design report.

- b. Gross content of material preserved was:

(1) Engineering Operations Report, N8610R:71-009, "NERVA Engine Auxiliary Support for INT-21 Launch and Boost"

(2) ANSC Drawing, 1138648, "Engine Support Frame-400E/EOS Concept"

- c. Degree of completion and major missing items was:

Two options of launch and boost vehicle existed for the NERVA system:

(1) INT-21 derivative of Saturn 5.

(2) Earth Orbital Shuttle (EOS).

Work was terminated on design and analysis of NERVA engine auxiliary support for INT-21 launch and boost per SNSO-C direction (See Appendix VI, Item 1) and documented by Item 2 of Appendix VI.

Efforts were directed to the launch and boost case with the E.O.S. but terminated by contract cancellation prior to completion. Refer to the discussion of Dynamics Analysis, Project 110-f-3.d(3) of this report, for the results of the analysis of the support for E.O.S. launch and boost.

d. Names of Personnel Performing the Work

B. Breindel, Dept 8610

H. J. Bronner, Dept 8160

I. Hall, Dept 8120

D. E. Kleinert, Dept 8610

2. Conclusions

The NERVA Engine as described by ANSC Drawing 1137400E requires an auxiliary support structure for launch and boost with an INT-21 or an EOS vehicle. The specific areas which were examined are the thrust structure, thrust vector system, pressure vessel, nuclear subsystem, nozzle assembly and external shield. Of these, the thrust structure, thrust vector system, and external shield require a support structure similar to that of Item 2 of Appendix VI. Verification of the ability of the nuclear subsystem to accept launch and boost loads is provided by Item 3 of Appendix VI.

The loads upon the engine by EOS launch and boost (Items 4 and 7 of Appendix VI) cause excessive deflections of the cantilevered portions of the engine supported per Item 5 of Appendix VI, Concept #2. This concept is described in greater detail by Item 6 of Appendix VI. The dynamics analysis discussed in Section 110-f-3.d(3) of this report indicated that the stiffness of this support frame was inadequate. The analytical model was modified to stiffen the support frame under advisement of the frame designer. The modification was not successful in eliminating excessive engine deflections (Item 8 of Appendix VI).

EOS launch load studies of the nuclear subsystem were incomplete when work was terminated, therefore no conclusions can be stated.

3. Recommendations

The excessive deflections of cantilevered sections of the engine for the EOS case can be resolved by utilization of damping devices to limit the amplitude of deflection, or by redesign of the support frame.

More comprehensive EOS dynamic properties data should be obtained to provide a better definition of the launch environment for the engine before continuing with the analysis.

4. References

See Appendix VI.

Project 110-f-3.i

1. Introduction

The purpose of the activity was to perform engineering activities on a propulsion module compatible with the cargo bay constraints of the EOS.

Material preserved documents the results of the Propulsion Module Study. The effort was directed toward determining the potential of modifying the 1137400E engine to obtain an improved configuration suitable for integration with the Class 3 Reusable Nuclear Shuttle (RNS). Details may be found in Appendix VII.

Personnel Assigned:

B. Breindel

W. A. Lester

K. E. Unmack

2. Conclusions

The referenced report summarizes the work performed and forms a basis for future RNS/Nuclear Rocket Engine integration studies.

3. Recommendations

None

4. References

See Appendix VII

APPENDIX I
REFERENCES FOR PROJECT 110-f
PARAGRAPH 3.a

The reference material for Project 110-f Paragraph 3.a is contained in this appendix and is as follows:

1. ANSC Drawing 1137400 Revision E "75K NERVA Flight Engine Layout - Full Flow"
2. ANSC Drawing 1137401 Revision F "75K NERVA Flight Engine Flow Diagram - FFE"
3. ANSC Letter N4110:0067 dated 26 February 1971,
AD Cornell from WE Stephens, Subject: State Points for the 1137400 Revision E Reference Engine.
4. ANSC Specification No. CP-90290C "Detail Specification Part I Performance/Design and Qualification Requirements for Engine, NERVA, 75K, Full Flow", dated 19 July 1971

APPENDIX II
REFERENCE FOR PROJECT 110-f
PARAGRAPH 3.c

The reference material for Project 110-f Paragraph 3.c is contained in this appendix and is as follows:

1. ANSC Drawing (no number) "Support Concept - TIL or TDL Attach - Thermal Displacement"
2. Outline for Engine and Component Status Review Section K.5 Structural Analysis/Stress (J. G. Schumacher).
3. ANSC Memo 4310:010 dated 5 Nov 1970 AD Cornell from JG Schumacher, Subject: Engine 1137400C Propellant Feed System Static Analysis Results.
4. ANSC Memo 7770:M:7327 dated 6 Oct 1970 A.D. Cornell from K.E. Unmack, Subject: Engine/Line Analysis.
5. ANSC Drawing 1138645 3 Sheets "Support Bracket Concept (1137400 E PFS)"
6. ANSC Memo N8610:033M dated 15 July 1971 U.A. Pineda from W. E. Stephens, Subject: Engine and PFS Support Designs.

APPENDIX III

REFERENCES FOR PROJECT 110-f

PARAGRAPHS 3.d (1 thru 5)

1. Engineering Operations Report, N8110R:72-034, "75K NERVA Thermal and Fluid Flow Analysis," dated 19 May 1972.
2. ANSC Structures Report, AM-PF-0005, "PFS Static and Dynamic Loads and Accelerations" dated 31 January 1972.
3. Engineering Operations Report, N8120R:72-027, "NERVA 400E Thrust Train Dynamic Analysis" dated 14 April 1972.
4. Engineering Operations Report, N8120R:71-010, "TPA/Lines Interface Loads for Malfunction Operation Condition" dated 21 October 1971.
5. Project Report 110-f-3.d(5), Mass Properties Analysis (S-047), H. J. Bronner, dated 29 March 1972.
6. Memo N8120:117, I.K. Hall to D. E. Kleinert, dated 22 March 1972, Subject: Transmittal of Summary of Analysis for Project 110 Report.
7. Memo N8110:M1766, W. R. Thompson to D. E. Kleinert, dated 29 Mar 1972, Subject: Transmittal of Section 1.0, Introduction, and Section 2.0, Summary and Conclusions of Engineering Operations Report N8110R:72-034, 75K NERVA Thermal and Fluid Flow Analysis, for Project 110.
8. Memo N8610:117M, W. E. Stephens to A. D. Cornell, dated 20 Jan 1972, Subject: 400E PFS Structural Analysis.
9. Memo N8610:115M, K. E. Unmack to A. D. Cornell, dated 19 Jan 1972, Subject: Format and Content for Engine S-036 Report.

10. Memo N8610:116M, W. E. Stephens to U. A. Pineda, dated 19 Jan 1972,
Subject: Documentation of Engine Level Applied Mechanics Effort.
11. Memo N8120:106, D. F. Vronay to K. E. Unmack, dated 20 Dec 1971,
Subject: Modal and Geometry Data Requested by McDonnell/Douglas.
12. Memo N8610:109M, W. E. Stephens to U. A. Pineda, dated 22 Dec 1971,
Subject: Dynamics, Loads and Structural Analysis.
13. ANSC Structures Report, AM-PF-0002, "PFS Static Interface Loads"
dated 1 April 1971.
14. Memo N8610:072M, J. H. Oates to J. G. Schumacher, dated 7 Oct 1971,
Subject: TPA Malfunction Line Temperatures.
15. ANSC Memorandum N8610:081M dated 25 Oct 1971, W. E. Campbell
from A. D. Cornell, Subject: Engine Weight Status.
16. ANSC Memorandum N8610:027M dated 29 June 1971, J.R. DaVolio from
W. E. Stephens, Subject: Target Mass Properties.
17. ANSC Memorandum N4110:0090M dated 13 April 1971, R. W. Froelich
from H. J. Bronner, Subject: NERVA Engine and Components Target
Weight Update.
18. WANL Letter SI:RL0:1630 dated May 14, 1971, J. L. Dooling,
Attention: W. E. Stephens/H. J. Bronner, ANSC, from R.F. Dickson,
Subject: Post PDR NSS Weights and Mass Properties.
19. WANL Letter DI:CMB:1647 dated June 17, 1971, J. L. Dooling,
Attention: A.Cornell/J. DaVolio/J. Smith, ANSC, from R. F. Dickson,
Subject: NERVA Nuclear Subsystem Assembly Layout.

20. ANSC Memorandum N8610:041M dated 3 August 1971, U. A. Pineda from
W. E. Stephens, Subject: Engine Weight Data for Dynamics Analysis.
21. Detail Weight Statement (400E Engine) (4 pages).

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APPENDIX IV
REFERENCES FOR PROJECT 110-f
PARAGRAPH 3.f

The reference material for Project 110-f, Paragraph 3.f, is as follows:

- *1. Engineering Operations Report N8000R:71-002, dated May 1971, "Engine/Component Design Status Review, Phase I - Four Ongoing Components, April 6-8, 1971, Presentations, and Phase II - Engine Methods and Ongoing Components, Presentations to SNSO, May 11-14, 1971".
- *2. NERVA Status Report N8000R:71-008, "NERVA Program Semi-Annual Status Review", dated November 1971.

*Material in SNSO-C files.

APPENDIX V
REFERENCES FOR PROJECT 110-f
PARAGRAPH 3.g

The reference material for Project 110-f Paragraph 3.g is contained in this appendix and is as follows:

- | | | | | |
|-----|---|---------------------------------|----------|----------|
| 1. | ANSC Drawing 1139701 | "Engine Concept Study - Radial" | 7 Sheets | |
| 2. | " | 1139702 | " | 3 Sheets |
| 3. | " | 1139703 | " | 4 Sheets |
| 4. | " | 1139704 | " | 4 Sheets |
| 5. | " | 1139705 | " | 3 Sheets |
| 6. | " | 1139706 | " | 5 Sheets |
| 7. | " | 1139707 | " | 3 Sheets |
| 8. | " | 1139708 | " | 3 Sheets |
| *9. | ANSC Report N8000R:71-008 "Semi-annual Status Review" | | | |
| | dated November 1971. | | | |

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*Material in SNSO-C files.

APPENDIX VI
REFERENCES FOR PROJECT 110-f
PARAGRAPH 3.h

1. SNSO-C letter to ANSC dated May 27, 1971, E. D. Ward from R. W. Schroeder, Subject: Technical Directive 71-20.
2. ANSC letter N8610:036L dated 25 August 1971, R. W. Schroeder from J. T. Paul, Subject: Auxiliary Support of NERVA Engine During Launch and Boost, E/CDSR Action Item No. 15 - Engine System.
3. WANL letter SD:RB:2354 dated September 21, 1971, J.-L. Dooling from R. F. Dickson, Subject: IED No. 009.
4. SNSO-C Magnafax Transmittal 3 August 1971, Subject: EOS Loads, J. E. Richardson to Ira Hall.
5. ANSC Drawing 1138646, "400E/EOS Launch Support Frame Concept."
6. ANSC Drawing 1138648, "Engine Support Frame - 400E/EOS Concept."
7. McDonnell/Douglas Astronautics Co. Letter A3-830-BSE0-L-18 dated 18 October 1971, James W. Russell, NASA, from S. Gronich, Subject: Transmittal of RNS Propulsion Module Dynamic Properties.
8. ANSC Letter N8610:118L dated 31 January 1972, R. W. Schroeder, SNSO-C, from J. T. Paul, Subject: Response to Action Item No. 15, Engine/Component Design Status Review Meeting, 10 May 1971.